# A Study on the Weldability of Fiberglass Reinforced Polyethylene

Hiroshi KIMURA*, Takuzi YAMAGUCHI*, Masaki IMACHI*,

Masakazu UEMATSU*, Giichi KAWASHIMA*, Eiji WATANABE*

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In this paper we describe an experimental study of the molding property and weldability of fiberglass reinforced thermoplastics. Ultrasonic welding presented the good results when fiberglass content was small.

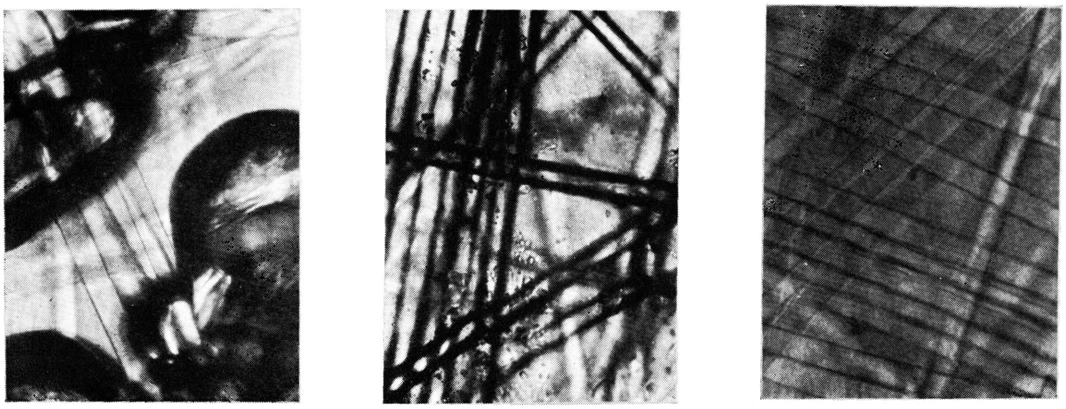
## INTRODUCTION

In the present paper, we will try to study the molding property and the weldability of F.R.T.P.. F.R.T.P. is the composite material, i.e. the reinforced engineering plastics and the polymer is its main matrix. It presents a complex property because of the reason that glass fiber is mixed as the reinforcing agent with polymer (that has the organic physical property). Therefore its coalescence (for example, molding or welding) becomes one of the difficult and serious problems. However the reinforc ement of engineering plastics is one of the important problems to be solved as the future study of engineering materials of plastics and, above all, the bonding of F.R.T.P is the subject one should not ignore.

## EXPERIMENTAL RESULTS AND CONSIDERATION

Fiberglass reinforced thermoplastics used for experimental study had the low density polyethylene as the matrix, random mat of glass fiber as reinforcing agent and welding was made on it. Bonding agent of glass mat was eliminated by dipping it in M.E.K. liquid for 1 hr.. Glass mat was then laminated on the central part of polyethylene film in a sandwitch shape, drying it at 80°C for 0~17 hr.; then keeping it under the pressure of 300 kg/cm$^2$ by hot press at 180°C for 15 min. and after gradually cooling it to 100°C, cooling it in the air. Fig. 1 shows relations obtained by this experiment between tensile strength of the F.R.P.E. and drying conditions. Photo. 1 shows the microstructure of F.R.P.E. obtained in the way described above. Big void has been observed from the non-drying treatment specimens at the boundary between glass fiber and P.E.. (a) shows this fact. This is obviously because of the effect of moisture attaching to the surface of both glass fiber and P.E.. (b) shows the sign of great improvement, obtained from drying the specimens at 80°C for 1 hr., in comparison

* Dep. of Textile Eng.



(a)
Non pretreatmen :

(b)
Drying condition :
80°C
1 hr.

(c)
Drying condition :
80°C
4 hr.

Photo. 1 Microstructure of F. R. P. E.

with (a) non pretreatment result.

But the bonding at the boundary between glass fiber and P. E. is not yet satisfactory. (c) is the result of the experiment drying the specimens at 80°C for 4 hr.. The bonding between glass fiber and P. E. is satisfactory. From the result of the preliminary investigation, Photo. 1, specimen (c) were used throughout this investigation. Fig. 2, shown the study of the strength and the direction of F. R. P. E., was the necessary results when random mat was used as reinforcing agent, and this confirms that the impregnation and the diffusion of P. E into glass fiber. in all direction were sufficient. Next study presents relations between thickness and tensile strength of F. R. P. E. of which glass content is 30% (wt. %). As is evident from Fig. 3, its strength reduces slightly in accordance with thickness increasing. The cause for this seems to be the size effect as well as the effect coming from the laminate method of F. R. P. E.. Namely, it might be the result that, owing to glass mat being laminated among P. E. could not sufficiently cover glass fiber under the same molding conditions (temperature, pressure, time,). Fig. 4 shows relations between tensile strength and glass content (weight %) of the 0.2 mm F. R. P. E.. Volume

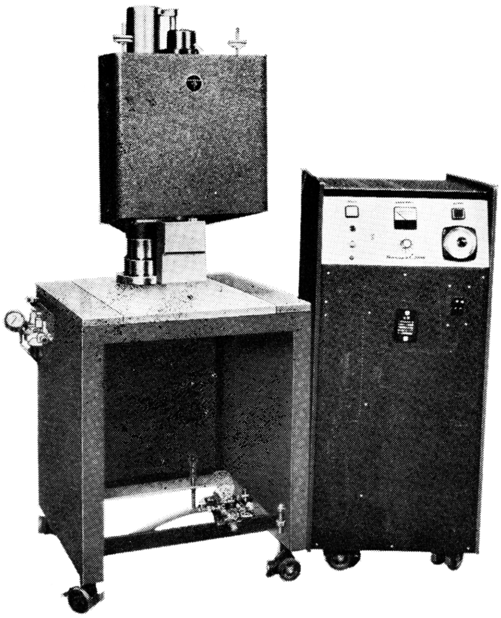


Photo. 2 Ultra-Sonic Welder

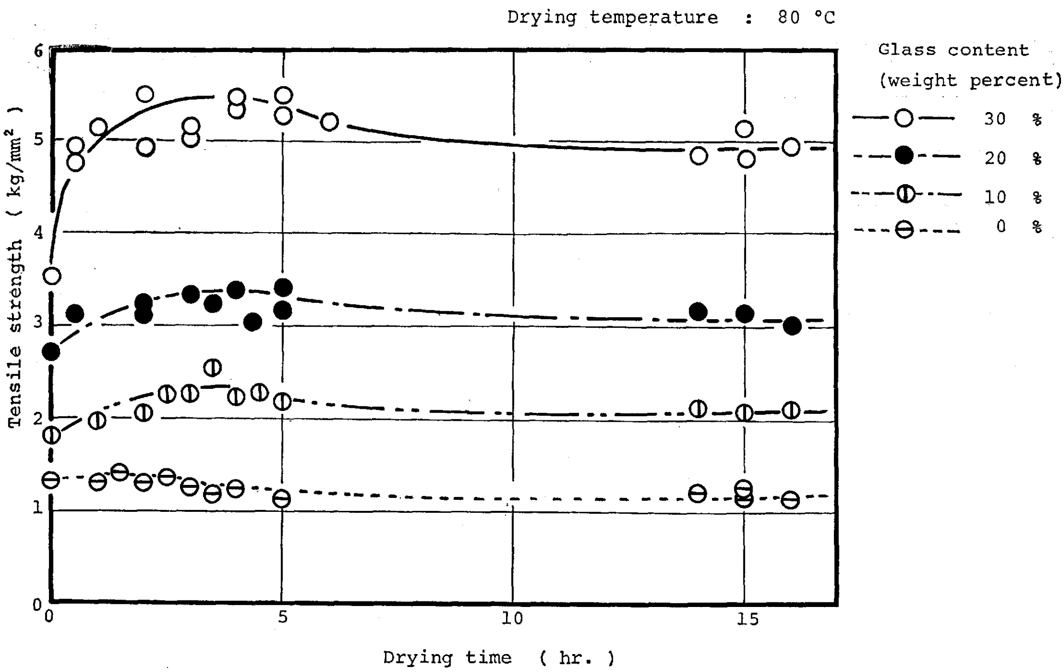



Fig. 1 Relation between drying time and tensile strength for F. R. T. P. (P. E.) with various contents of glass fiber

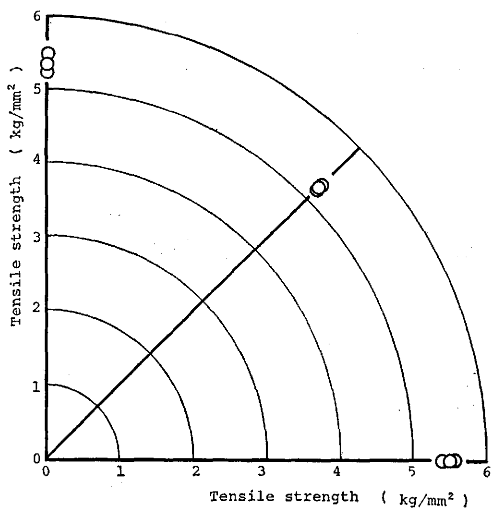



Fig. 2 Relation between tensile strength and directional property of F.R.T.P. (P.E.)

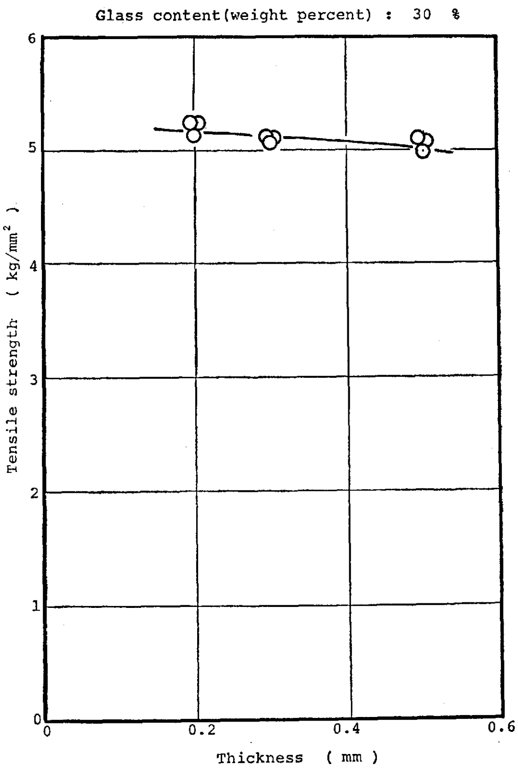



Fig. 3 Relation between thickness and tensile strength for F.R.T.P. (P.E.)

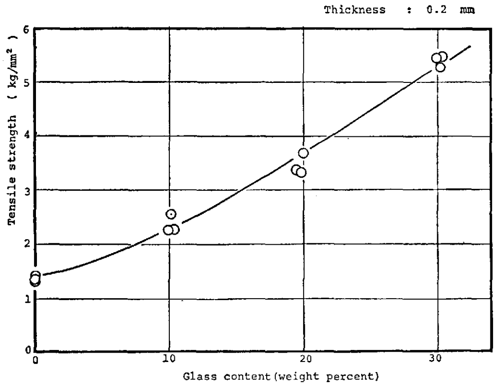



Fig. 4 Relation between glass content and tensile strength for F.R.T.P. (P.E.)

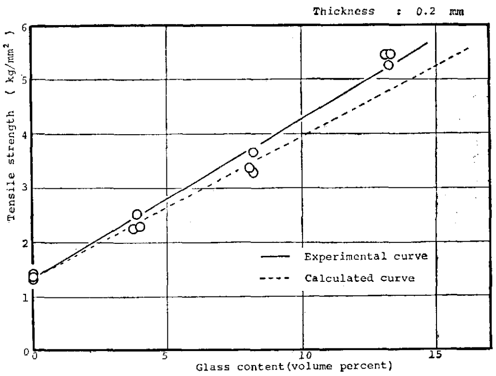



Fig. 5 Relation between glass content and tensile strength for F.R.T.P. (P.E.)

% of the same results is presented by Fig. 5. It becomes clear from these experimental results that the linear correlation was recognized between glass content and tensile strength in the small extent of glass fiber. Next study is the application of law of mixture to this F. R. P. E.. Tensile strength of F. R. P. E. is approximated to (1) under the law of mixture[1].

$$\sigma_c = K \cdot \sigma_f \cdot V_f + \sigma_m \cdot V_m \quad \cdots\cdots\cdots(1)$$

Where, $\sigma_c, \sigma_f, \sigma_m$ : Tensile strength of F. R. P. E., fiber glass and P. E..

$V_f$, $V_m$ : Volume % of fiber glass and P. E..

K : Proportional coefficient.

Mr. Lees[1)2)] suggested the following 2 experimental equations. That is to say, for reinforced plastics of one direction fiber glass,

$$\sqrt{K} = 1.31 + 0.310 \log_{10}(E_m/E_f) \quad \cdots\cdots\cdots(2)$$

Where, $E_f$, $E_m$ : Young's modulus of fiber glass and P. E.. For asbest reinforced thermoplastics of random distribution.

$$\sqrt{K} = 0.65 + 0.145 \log_{10}(E_m/E_f) \quad \cdots\cdots\cdots(3)$$

Same correlation was demonstrated between $\sqrt{K}$ and $\log_{10}(E_m/E_f)$ in the random distribution of F. R. P. E.. We then assumed the equation (4) and applied this to F. R. P. E. thus obtained.

$$\sqrt{K} = 0.98 + 0.228 \log_{10}(E_m/E_f) \quad \cdots\cdots\cdots(4)$$

And then, $E_m = 24$ kg/mm², $E_f = 156$ kg/mm²

So that, insert to (1) equation.

$$\sigma_c = 26V_f + 1.35 \quad \cdots\cdots\cdots(5)$$

Where, $V_m = 1 - V_f$

Broken line shows the calculated value got from the equation (5). Next we studied the weldability of F. R. P. E. obtained in the way mentioned above, using ultrasonic welder. Ultrasonic welder used for this experiment was made by SEIDEN SHIYA DENSHIKOGYO Co., Ltd., shown in Photo. 2 and its frequency was 20 KHz, Power 1000W. Ultraasonic welding seems to be achieved in the following way. Bonding surfaces of the two plastics get nearer mutually to the extent of bonding force among polymers by heat softening or melting phenomena caused by ultrasonic vibration of plastics. That is to say, ultrasonic heating effect is considered to be initiated both by heat induced from internal strain caused by compressive vibration and by heat only near the bonding surface caused by the strong stress of surface introduced by collision between the little gap of bonding surfaces. We continued the experiment under the assumption that P. E. bonding at the F. R. P. E. boundary surface proceeds by heat from the inner parts of platics caused by ultrasonic vibration and by heat of the surface, and that the coalscence be made in accordance with the progress of mutual diffusion of glass fiber caused by static load. Fig. 6 shows the positional relations between horn, anvil and welding specimen. The parameters used for the welding experiment are the pressure on weld part and ultrasonic supplied time. Photo. 3 shows the good results of microstructure of weld obtained under various welding conditions. It is impossible to recognize the bonding surface from the photo showing the section of bonding surface. But it is observed that glass fiber diffused mutually on the non-continuous part of composite materials of weld, thus the continuity was recovered to some extent, and coalescence was made. Following study was the tension test of these welded specimens. Fig. 7 shows relations between welding conditions of P. E. film, 0.2 mm, in thickness, and joint efficiency. Fig. 8. Fig. 9. Fig. 10 show respectively relations between welding conditions and joint efficiency, under various % of glass content. Experimental results, shown in Fig. 7~10, commonly explain as followings. When the pressure is weak, the peak of joint efficiency is found at the point of welding time being long. (3~5 sec.) and when the pressure is increased the peak is found at the point of welding time being short. (1~2 sec.) When the welding time is long, softening on the bonding surface becomes enough and as welding going on, thickness of the weld becomes thin, and then tensile strength decreases. This may be also concluded by the fact that lots of failures be observed at the boundary of weld, namely, the corner. Regarding this point, we search for the correlation between the strength and the rate of weld thickness for base material thickness. Results are shown in Fig. 11 under various glass contents. This figure explains that joint efficiency reduces as the glass content increases and, irrespectively of glass content, themaximum joint efficiency

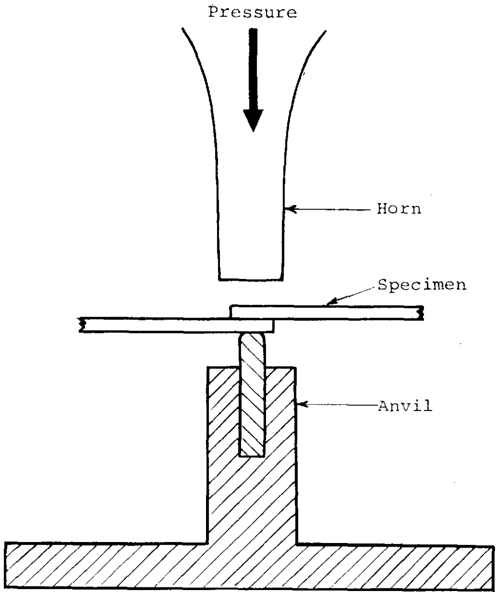


Fig. 6 Schematic diagram of apparatus for ultrasonic welding

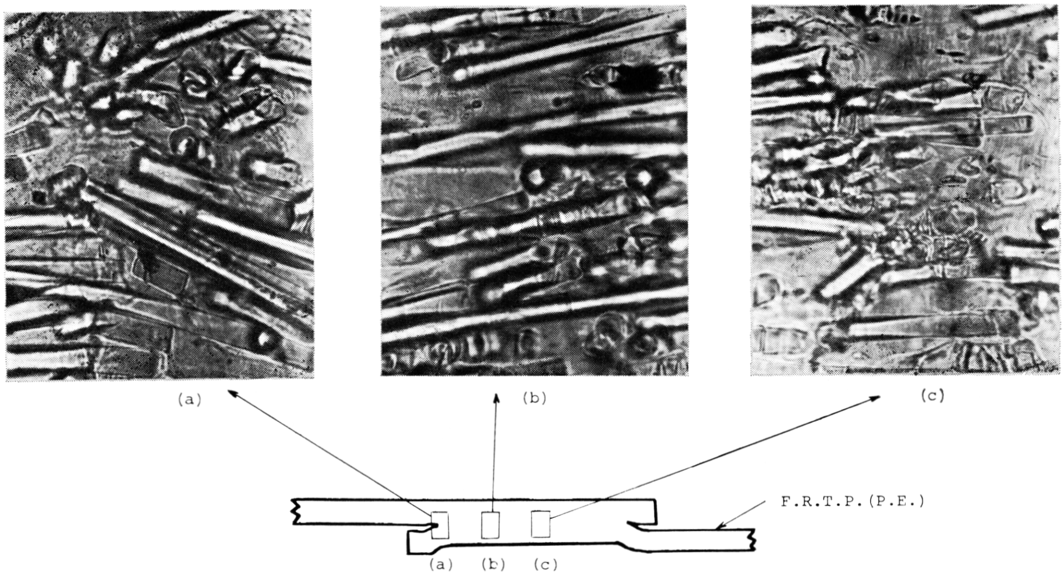



Photo. 3 Photograph of welded part

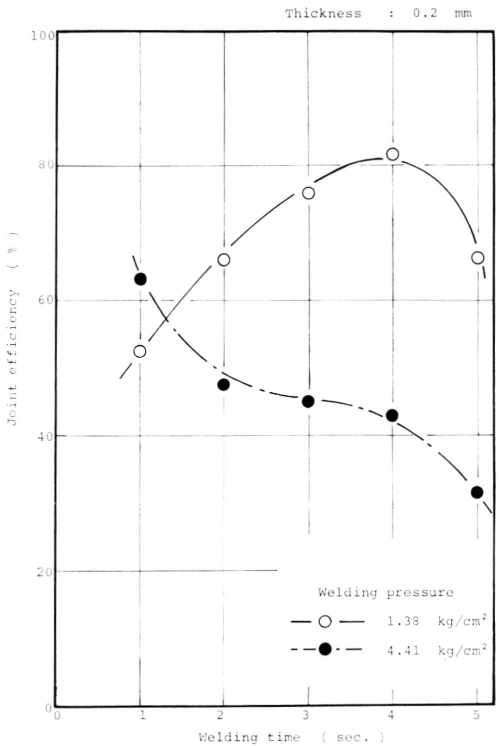



Fig. 7 Relation between welding conditions and joint efficiency for P. E.

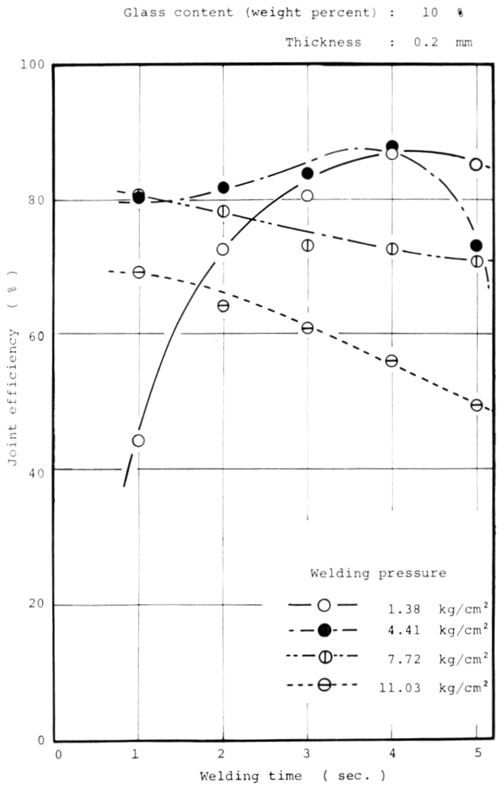



Fig. 8 Relation between welding conditions and joint efficiency for F.R.T.P. (P.E.)

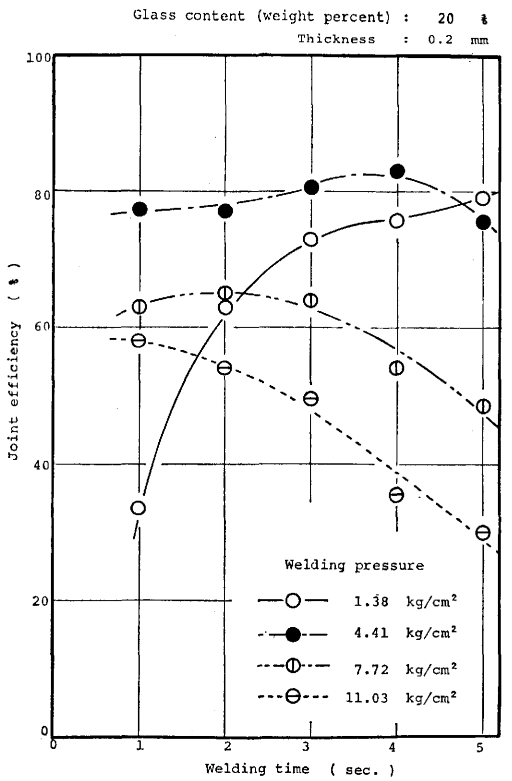



Fig. 9 Relation between welding conditions and joint efficiency fer F.R.T.P. (P.E.)

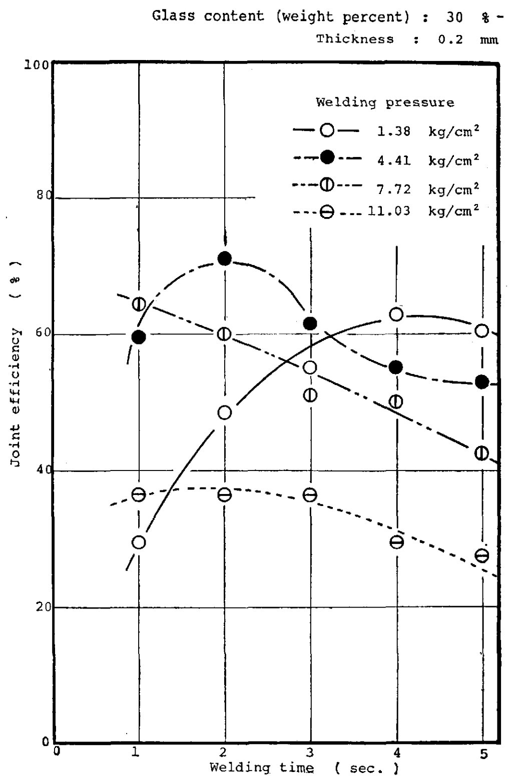



Fig. 10 Relation between welding conditions and joint efficiency for F. R. T. P. (P. E.)

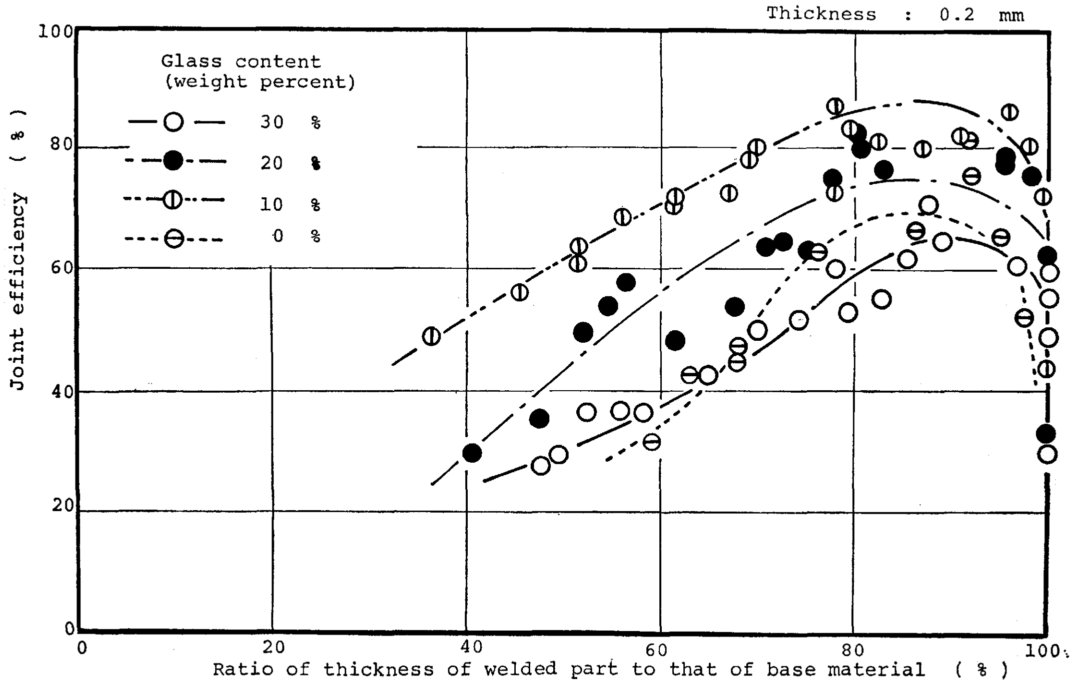



Fig. 11 Influence of thickness change of weld zone on joint efficiency (Effect of glass content)

is found at 85%~90% weld thickness. From the experimental results of Fig. 7~11, it becomes clear that ultrasonic welding of 0.2 mm F.R.P.E. is achieved as well as the straight P.E.. Fig. 12, 13 show relations between welding conditions of 30% glass content, 0.3, 0.5 mm F.R.P.E. and joint efficiency. Fig. 14 shows those of 0.5 mm P.E. films. These results are nearly the same as those of Fig. 7~10 (0.2 mm). Fig. 15 shows relations among Fig. 10, Fig. 12 and Fig. 13 using the weld thickness variation and the same method used for Fig. 11. As to the specimens 0.5 mm in thickness, the maximum value of joint efficiency is lower than the other.

## CONCLUSION

The following summary can be made from the results of the present experiments.

F. R. P. E. could get more than four times strength of P. E.. Ultrasonic welding presented the good results. As for 10% of glass content, good weld got nearly the same strength of F.R. P. E. base material by the mutual diffusion of glass fiber.

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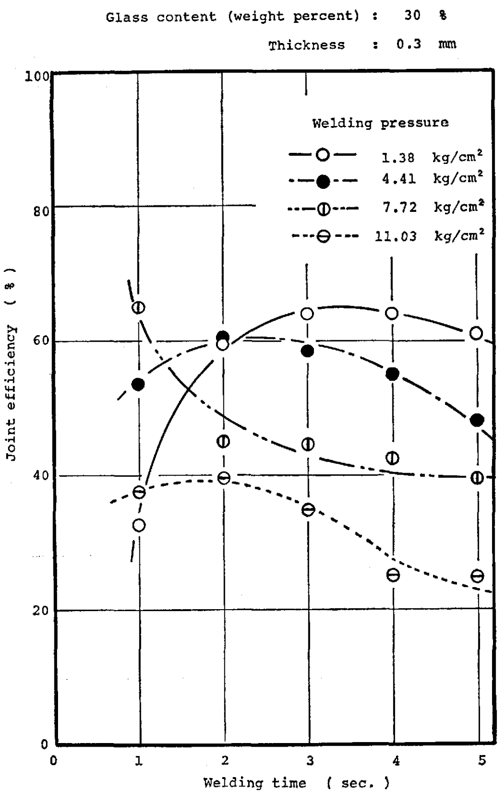


Fig. 12 Relation between welding conditions and joint efficiency for F. R. T. P. (P. E.)

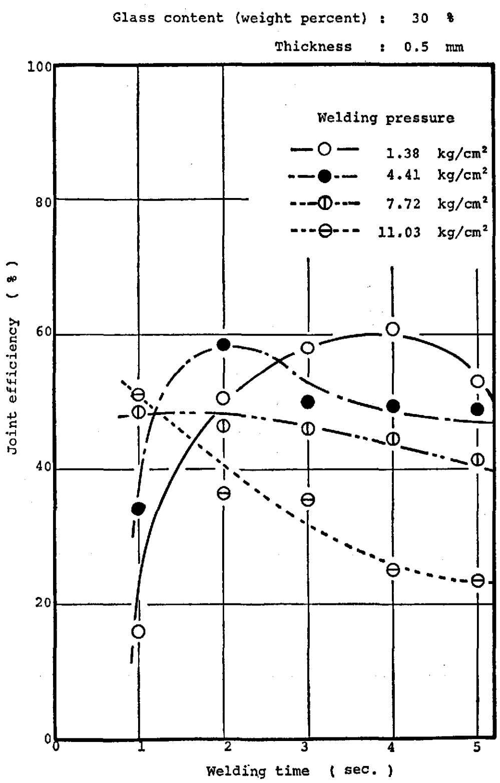


Fig. 13 Relation between welding conditions and joint efficiency for F. R. T. P. (P. E.)

Tutunaka Plastics Ind. Co. Ltd. for preparing to base materials.

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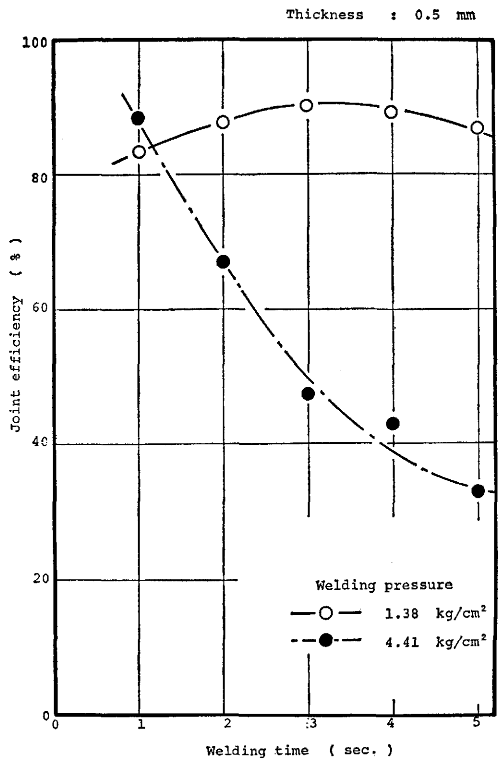


Fig. 14 Relation between welding conditions and joint efficiency for P. E.

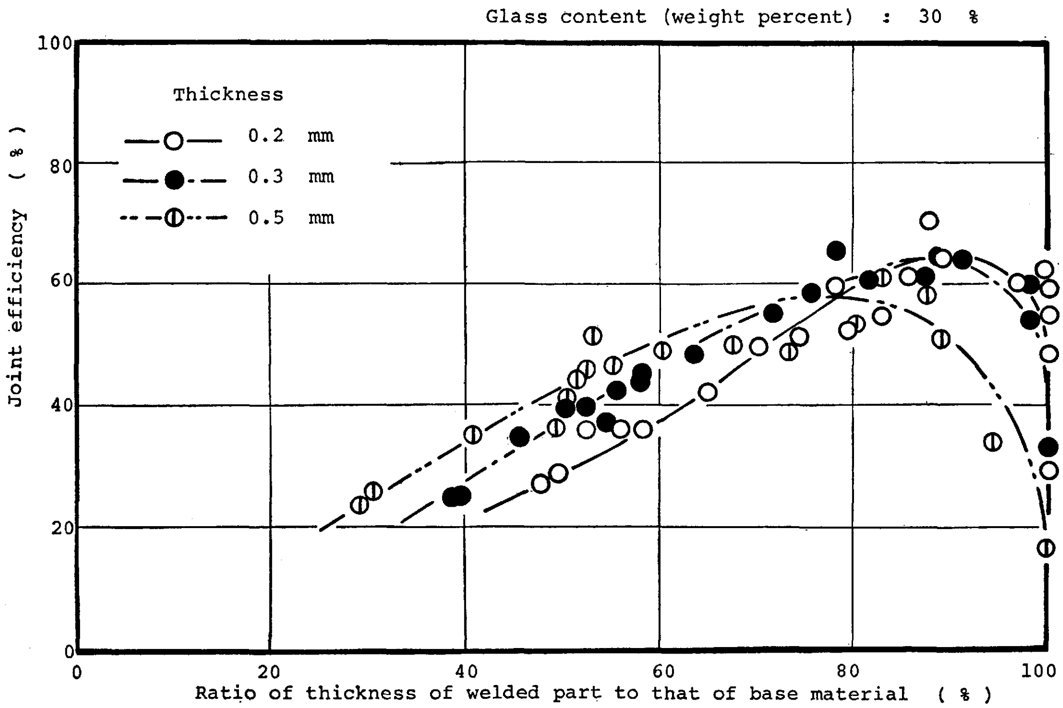


Fig. 15 Influence of thickhess change of weld zone on joint efficiency (Effect of film thickness)